Chapter 6

Cage Culture in Freshwater and Protected Marine Areas

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Cages are systems that retain the species cultured in a confined area, usually at high density, while excluding unwanted animals from the larger body of water. Cages depend on water movement through them (from the water body) to supply the culture organisms with water of sufficient quality for sustained growth and to remove problematic metabolic wastes. Historically, many of the failures of cage operations and environmentally founded criticisms of cage systems stem from improperly placing them at sites with poor water circulation (Stickney 2002). Sites with poor water circulation have led to low dissolved oxygen conditions and to the buildup of metabolic wastes causing poor water quality conditions, reduced growth, dense algal blooms, sediment contamination, devastation of benthic biota, disease outbreaks, and often significant mortalities.

The water bodies the cage or cages are placed in provide most basic functions needed to sustain culture. The temperature regime is that of the water body and may be fairly stable depending on location and volume of the water body. The concentrations and variability of water quality parameters depend on the water body, currents, and any external inputs. In particular, the delivery of dissolved oxygen and the removal and decomposition of wastes from cages depend on the water body and its physical, chemical, and environmental characteristics. In some cases (extensive culture), the water body provides food for the cultured species. Therefore, the success of cage culture is very dependent on the water body in which the cages are placed and environmental impacts on that water body from the culture practices, the climate, water quality, and possibly human activities.

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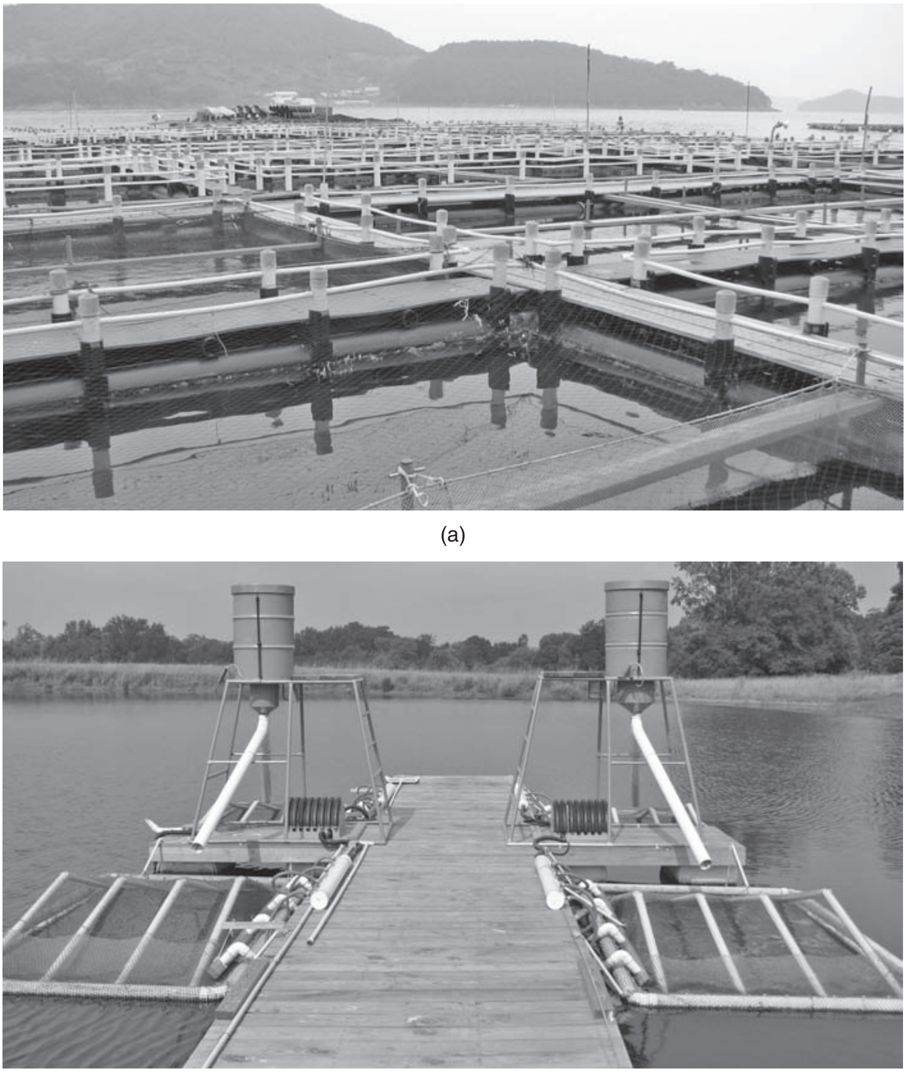

(a)

(b)

Figure 6.1 Large marine cage complex off South Korea (a) and small freshwater catfish cages in Texas, United States (b).

Strictly defined, cages are rigid structures or have a frame on which the netting or mesh is held in place while net pens utilize flexible netting or mesh with no complete or encasing frame. However, the terms cage and net pen are often used interchangeably with no regard to these distinctions (fig. 6.1 a, b)

Considering that over 70% of the Earth's surface is covered with water, the opportunity for cage culture should be obvious. This foreseen opportunity has led to many advances in cage design, species cultured, and production volume in recent years. This chapter will discuss the species currently being

cultured, the advantages and disadvantages of cage culture, and the management issues of cage aquaculture.

6.1 Current status of cage culture

In 2007, the United Nations Food and Agricultural Organization (FAO) Fisheries and Aquaculture Department held a Special Session on Cage Aquaculture and published a global overview on the status of cage aquaculture (Halwart *et al.* 2007). This FAO document divided the information by geographic regions (e.g., northern Europe, Latin America, etc.) with the exception of China, for which a country review was developed and included due to the recent expansion and magnitude of cage aquaculture in that country.

The FAO report was based on data available from 2005 with a total of sixty-two countries providing information (Tacon & Halwart 2007). While these data can in some cases be considered incomplete (not all countries reported) they are considered the best estimate of the scope and importance of global cage aquaculture to date.

Total global cage production was estimated to be approximately 3.4 million metric tonnes in 2005. Based on this report the countries that led in cage aquaculture were China, Norway, Chile, Japan, United Kingdom, Vietnam, Canada, Turkey, Greece, Indonesia, and the Philippines (Tacon & Halwart 2007). While China led in total cage production, it was only 2.3% of total Chinese aquaculture by volume (Chen *et al.* 2007). By contrast, Canada reported almost 70% of its production by volume was from cages (Masser & Bridger 2007).

Finfish species cultured in cages are predominately high-valued species. The vast majority of finfish cultured in cages are carnivorous species requiring high-protein, high fish-meal diets. These include salmon (Atlantic, *Salmo salar,* Coho, *Oncorhynchus kisutch,* and Chinook, *O. tshawytscha*), seabass (*Dicentrarchus labrax* or *Lates calcarifer*), seabream (*Sparus aurata*), amberjack (*Seriola* spp.), snapper (*Cromileptes* and *Epinephelus* spp.), cobia (*Rachycentron canadum*), rainbow trout (*O. mykiss*), mandarin fish (*Siniperca* spp.), and snakehead (*Channa* spp.). However, the culture of omnivorous species in cages is expanding and includes species of carps (*Cyprinus carpio, Hypophthalmichthys molitrix, Aristichthys nobilis,* and *Ctenopharyngodon idella*), tilapia (*Oreochromis* spp.), *Colossoma,* and catfish (*Pangasius* spp.; Tacon & Halwart 2007). Globally, five families of finfish (i.e., *Salmonidae, Sparidae, Carangidae, Pangasidae, and Cichlidae*) make up 90% of all cage production. Salmonids are the dominant cage cultured species by both volume (66%) and value (>US$4.7 billion; Tacon & Halwart 2007).

Cage aquaculture is practiced at all socio-economic levels. The diversity of cage producers ranges from artisanal farmers producing for their families, to family enterprises, to large industrial scale farms utilizing both private and public waters (De Silva & Phillips 2007; Masser & Bridger 2007). Commercial cage culture has expanded rapidly since the Norwegians developed modern salmon farming methods in the 1970s. Salmonids cage farming grew from a production

of only 294 tonnes in 1970 to 1,235,972 tonnes in 2005 (Tacon & Halwart 2007). Counties leading this dramatic expansion were Norway, Chile, and the United Kingdom. The development of new cage designs and emerging species, especially marine, has led to expanded interest in cage aquaculture. This expansion is particularly notable in developing countries with tropical climates, and continued growth is anticipated (Tacon & Halwart 2007).

6.2 History and evolution of cage culture

Cages were undoubtedly first used as holding and transporting pens for wild caught fish and shellfish awaiting sale (Beveridge & Little 2002). The actual culturing of fish in cages supposedly was first practiced in China during the Han Dynasty (100 to 200 BC; Li 1994). Most of the early cages were constructed of wood or bamboo and some used cloth to hold and culture fry (Hu 1994). Feed consisted of human food scraps & trash fish (Beveridge 2004). This type of cage culture has been practiced for centuries and is still practiced in parts of Asia (Halwart *et al.* 2007). For a more complete review of the origins of cage culture see *Cage Aquaculture* by Malcolm Beveridge (2004).

Cages have been utilized for all stages of aquaculture production: holding broodstock, spawning, rearing fry and fingerlings, and production of foodfish. Cage mesh size is chosen based on the size of fish at stocking and often fish are moved to cages of larger mesh size as they grow. In general, fish should be stocked in the largest mesh size that will retain them. Tilapias are often spawned and the fry reared in fine-meshed cages called "hapas" (fig. 6.2; Smith *et al.* 1985).

Figure 6.2 Hapas for rearing of fish fry.

While cages are used to produce fingerlings of many species, their primary use is for growout to market sizes (Beveridge 2004).

Cages have also been utilized in research and environmental monitoring. Cages have been adopted for nutrition research in order to eliminate or minimize the fish's consumption of other foods (Stickney 1979; Webster *et al.* 1994) or to monitor water quality (Chamberlain 1978; Grizzle *et al.* 1988).

Cages can be categorized as extensive, semi-intensive or intensive based on their stocking density and source of food (Beveridge 2004). Extensive cages receive no external feed and rely on only natural foods such as plankton (phyto and zoo), seston, and detritus. Extensive cage systems have usually been placed in highly eutrophic freshwater lakes, reservoirs, and some sewage effluent lagoons in order to take advantage of the natural productivity (Costa-Pierce & Effendi 1988; Edwards 1992). The species cultured extensively have been primarily carps and tilapias (Li 1994; Costa-Pierce 2002). Extensive cage production can yield up to 1.9 kg/m^3 per month (Beveridge 1984).

Semi-intensive cage culture is very common in freshwater systems in tropical climates (Beveridge 2004). Like extensive culture the species commonly cultured include the tilapias and the carps (i.e., silver, bighead, grass, and common). In addition to available natural foods, the fish are fed other (usually nutritionally incomplete) foodstuffs. These have included food scraps, rice bran, brewery byproducts, wheat middlings, and other agricultural byproducts (Pantulu 1979; De Silva 1993; McAndrew *et al.* 2002). Semi-intensive production in cages can yield over 100 kg /m^3.

Intensive cage culture requires the use of nutritionally complete feeds. Intensive culture usually is limited to high-valued species because of the cost associated with feeding. In freshwater these include catfish (Ictalurids and Pangasids), salmonids, snakeheads, carps, and tilapias. In marine waters, species cultured include salmonids, seabass, seabream, yellowtail, amberjack, cobia, and croaker. Increasing interest in cage culture of other marine species such as tuna, grouper, and snapper has begun. Yields in intensive cages are greatest and can be in the range of 250 to 600 kg/m^3 (Schmittou *et al.* 2004).

6.3 Advantages and disadvantages of cages

All culture systems have advantages and disadvantages. Advantages of cage aquaculture include the exploitation of almost any existing water body (e.g., ocean, bay, estuary, river, lake, or pond); relatively low construction costs compared to building ponds, raceways, or recirculation systems; observation, feeding, and harvest are relatively straightforward; and disease treatment (if necessary) can be effected more accurately and economically (Masser 2008).

Most disadvantages associated with cages can be attributed to the relatively high densities that culture species are stocked. These can include crowding related abrasions, rapid disease spread, localized water quality issues, attractiveness to predators and poachers, and communal interactions of the cultured species that

may cause reduced growth (Masser 2008). Fouling of the cage netting is also a common problem. Fouling organisms can diminish the volume of the cage and severely decrease water flow circulation through the cage. Fouling organisms can include algae or sessile organisms such as bryozoans and sponges. Often cages have to be periodically scrubbed or the netting replaced to cope with this problem (Milne 1970). In addition, cage culture has little or no control over water quality parameters like temperature, pH, alkalinity, and hardness. Dissolved oxygen can be supplemented with aeration or circulation devices and location (i.e., currents and depth) can influence the concentrations of particulates and nitrogen waste products in and around the cage (Masser 1997a, b; Beveridge 2004; Masser & Woods 2008).

Another possible disadvantage to cage culture, if public waters are to be used, can be permitting. Most countries require permits to place and operate cages in public water. The requirements to obtain permits vary greatly from country to country and can include the preparation of environmental impact assessment and public hearings. Currently in the United States, for example, it is extremely difficult to obtain permits for cage culture in public waters and legislation to streamline the process in federal waters has not been passed by the United States Congress (Masser & Bridger 2007).

6.4 Site selection

Cage production is a very attractive culture system where existing water bodies can be utilized with little or no economic costs. However, the proper siting of cages is essential for their functionality, particularly in relation to proper water quality within the cage and reduced environmental impacts around the cage. Research on actual site characteristics and modeling of water currents and waste dispersion may be used to help predict impacts from cages in public waters (Landless & Edwards 1977; Ervik *et al.* 1997; Turner 2000; Stickney 2002; Olsen *et al.* 2005; Belle & Nash 2008).

Cage culture confines fish or shellfish at relatively high densities but relies on the surrounding water body to maintain suitable water quality within the cage and to perform functions of waste removal (Stickney 2002). When sited in unsuitable locations, cages have caused environmental degradation to the surrounding waters and benthic zone (Axler *et al.* 1992, 1994; Kelly 1995; Tsutsumi 1995). This reliance on the water body to provide ecosystem functions to private aquaculture ventures in public waters has, at times, led to conflicts with local communities and environmental groups, often resulting in negative publicity (Lumb 1989; Stickney 1990). Most criticisms of cages located in public waters are related to possible water pollution, escapement, benthic community alteration, spread of diseases to native populations, navigation issues, or simply the aesthetics of seeing the cages from the shore (referred to as “sight” or “visual” pollution; Stickney 1990, 2002).

6.5 Stocking cages

The densities of cultured species stocked in cages are highly variable and little research has been done to establish optimum stocking densities for many species (Beveridge 2004). Fish can either be stocked at the density needed to reach final production goals (i.e., desired number and harvest size minus anticipated mortalities) or in a two-stage process wherein small fish can be stocked at high densities and then restocked into additional cages at lower densities as their biomass increases. Which strategy is used often depends on the length of time it takes to get fish to the final desired market size.

Often cages are discussed in terms of fish density versus cage volume. In general terms, cages can be low-density/high-volume or high-density/low-volume. Marine cage culture operations are usually low-density/high-volume. In these cases, densities of 5 to 20 fish/m^3 are common, realizing that often the desired harvest size is several kilograms (e.g., Atlantic salmon are usually harvested at 4 kilograms or larger).

High-density/low-volume cages are more common in freshwater cage culture. In these systems cages are often stocked at densities of 150 to 450 fish per cubic meter with the target harvest weight of one kilogram or less (fig. 6.3). Species commonly cultured at these densities include catfish, tilapia, carps, and other freshwater species (Schmittou 1993; Duarte *et al.* 1993; Masser 1997c). These higher densities are often necessary for some species (like channel catfish) to minimize aggressive interactions, which may occur at lower densities (Masser 2004).

Figure 6.3 Channel catfish shown at a common density of 50 kilograms per cubic meter to illustrate fish density in low volume cages.

6.6 Feeding caged fish

In semi-intensive and intensive cage culture, feed costs represent 25 to 50% of total production costs (Beveridge 2004). Feeds must meet nutritional requirements, be palatable and of appropriate size, and not pollute the environment to the point of causing deleterious consequences.

As with most culture systems, caged fish are fed based on fish size, water temperature, and feeding response. In semi-intensive cage culture numerous kinds of feedstuffs have been utilized in the diets (Lovell 1989; New *et al.* 1993; Beveridge 2004). Development of modern intensive culture diets did not begin until the 1950s (Lovell 1989) and have yet to be formulated for many desired culture species. "Trash fish" (i.e., fish of little commercial value, rarely consumed by people, and would otherwise be discarded) and invertebrates are often fed to certain species in areas where formulated diets are are too expensive or too difficult to obtain. Common problems associated with feeding trash species include availability, nutritional suitability, storage, seasonal quality, and possible introduction of diseases (Beveridge 1984; Tacon 1992; Wu *et al.* 1994). The utilization of trash species and high fish meal and fish oil content in diets may be a concern and is often a criticism of aquaculture (Tidwell & Allan 2001; Pike & Barlow 2003; Belle & Nash 2008).

Over or underfeeding can be problematic in any type of culture system and can be particularly challenging in cage culture. Feed can quickly wash out of cages due to currents or, in the case of sinking feeds, can fall through the cage. For these reasons caged fish are often hand fed, fed by automatic fixed-ration systems, fed utilizing demand feeders, or the cages can be equipped with interactive systems that monitor feeding activity and adjust feeding rate to accommodate appetite (Beveridge 2004; fig. 6.4). In the salmonid industry improvements in feed formulation, manufacture, and automated feeding systems have greatly improved feeding efficiencies so that feed conversion ratios have decreased from around 2.5:1 in the 1970s to below 1:1 by 2005 (Grøttum & Beveridge 2007).

Fish behavior must also be considered and many species of fish have preferred feeding times. Channel catfish, like many other species, are crepuscular (i.e., dawn and dusk) feeders and will consume more feed and grow faster if feed in low-light conditions (Woods 1994).

6.7 Polyculture and integrated systems

"Polyculture" involves culturing more than one species in the same cage while "integrated culture" involves using more than one aquaculture system in association to culture multiple species. With polyculture the species may or may not directly benefit from the other and may actually compete. With integrated culture the species benefit in some way from the presence of the other. Cage polyculture has been limited in application mostly because of species' competition for

Figure 6.4 Hand feeding of sea bass in cages off Corsica.

whatever natural food or artificial feed is applied. In China, polyculture of silver carp and bighead carp (both plankton feeders) in cages has been practiced since the 1970s (Chen *et al.* 2007). Often, common carp or tilapia are also stocked into silver/bighead cages to reduce fouling (Chen *et al.* 2007).

Channel catfish have been successfully polycultured with rainbow trout and tilapia. In both cases the polyculture improved catfish growth and it was suggested that the other species stimulated increased feed consumption by the catfish (Williams *et al.* 1987; Beem *et al.* 1988; Woods 1994). Sea urchins have been placed in net enclosures hung inside Atlantic salmon cages and grew well feeding on waste feed (Kelly *et al.* 1998). Seaweeds have been cultured in shrimp cages in Brazil and provided shade and hiding places for the shrimp while benefiting from the shrimp wastes (Lombardi *et al.* 2001). Integrated culture of salmonids with seaweed and mussels has been practiced in Canada (Chopin & Bastarache 2002). The seaweed and mussels benefit from the fish wastes and significantly reduce the impact on water quality of the fish wastes, thus improving the overall environment.

6.8 Problems with cage culture

As noted previously, many problems associated with cage culture are related to the high stocking densities. Skin abrasions can occur as fish rub against cage materials or through fish/fish bumping or biting. Abrasions combined with stress

and high nutrient loads often result in the opportunity for diseases development and diseases spread rapidly at high densities (Masser 2004; Masser & Woods 2008). Feeding hierarchies, like pecking orders in poultry, are usually observed when densities are too low and lead to reduced feed consumption and slowed growth in subordinate animals (Schwedler *et al.* 1989; Lazur 1996). High densities and the associated high feeding rates can exacerbate water quality problems: especially, low dissolved oxygen, high ammonia, and increased turbidity. The potential effects of densities that are too low or too high illustrate the need for research to identify optimal densities for different species and cage types.

Other common problems associated with cage culture include net fouling. The nutrients from the feed and fish wastes stimulate the growth of algae and many other sessile or benthic type organisms, which attach to and colonize around the cage. Fouling of the cage reduces volume and can severely reduce water movement through the cage, which further exacerbates water quality, stress, and disease issues.

Currents and drifting debris pose additional problems in cage culture. While good water exchange is critical for maintaining a quality cage environment, excessive currents cause problems with moorings and deformation of cage structures and integrity (i.e., collars and netting), loss of feed, and stress on the fish. Currently, the maximum velocity of water is about 60 cm/s (Beveridge 2004). Drifting debris (e.g., logs, floating aquatic plants, etc.) can impede water movement, and deform, damage or destroy cages. Vigilant removal of drifting objects and deflection barriers are often employed to mediate this problem.

Genetics can play a significant role in selection or development of strains of fish well suited for cage culture. Selection of species strains that tolerate and thrive with confinement in cages and its associated stressors is critical for success of cage culture (Woods 1994). The salmon industry leads other cage farming industries in selecting fish with traits that prosper in the cage environment (Jobling 1995; Gjøen & Bentsen 1997). This is an area that needs much more research for many species before their successful cage culture can be achieved.

Cages can be attractive to other species in the water body as hiding places, attachment structures, and as sources of food (Oakes & Pondella 2009). Competitors, scavengers, and predators also are attracted to cages. Often wild fish will be attracted to the cage at feeding times and push against the cage netting trying to get to the feed. This often intimidates the culture fish and reduces their feeding activity (Woods 1994). Predators and scavengers can cut cage nets, releasing the culture fish into the wild (Rueggeberg & Booth 1989). The cage culture industry has had problems with seals, piscivorous birds, and many other species of fish, invertebrates (e.g., squid), reptiles, and mammals (Chua & Teng 1980; Quick *et al.* 2004). Cage damage, disease issues, and fish losses can have had significant economic impacts on cage operations (Nash *et al.* 2000; Würsig & Gailey 2002).

Finally, poaching and vandalism can be devastating problems in cage aquaculture in both public (Gooley *et al.* 2000) and private waters (Masser 1999;

Masser & Woods 2008). Security is an element that all cage operations must consider and plan for all contingencies.

6.9 Economics of cage culture

The costs associated with cage construction and mooring vary greatly upon depending materials and sizes used. As with many types of construction, the cost per unit volume generally decreases as size increases. Cage netting or mesh can be relatively inexpensive if plastic or fiber netting is used, but it increases considerably if coated welded wire, stainless steel, or copper-nickel mesh is utilized. High-energy environments also increase construction and mooring costs (Lisac & Muir 2000; Belle & Nash 2008; see chapter 7 for cages and net pens in offshore and high-energy environments).

Variable costs for cage operations can vary widely depending on size of operation, site, species, culture intensity, and management costs. As with most intensive culture systems, feed costs are usually the highest variable cost averaging around 50 to 60% of total costs. The nutritional requirements of the cultured species and transport costs can greatly impact feed costs. The second highest variable cost is usually seed or fingerling costs and can range from 10 to 40% of variable cost, dependent on the species cultured (Escover & Claveria 1985; Heen 1993; Marte *et al.* 2000; Woods & Masser 2009). Severe fouling, more problematic with marine cages, increases labor costs while wooden cages do not have as long a lifespan as cages constructed from plastics and metals.

In general, cage farms are less expensive to build and operate compared to other systems (Beveridge 2004). This has been documented in salmon (Shaw & Muir 1986; Heen 1993), sea bass and sea bream (Lisac & Muir 2000), and catfish (Collins & Delmendo 1979; Bernardez 1995). These analyses do not take into consideration any environmental costs associated with the ecological services provided by the surrounding cage environment (i.e., water quality and benthic alterations). These costs may be increasingly evaluated in the future and possibly recovered through environmental taxes.

6.10 Sustainability issues

Sustainability issues surrounding cage culture are similar in many ways to those of other aquaculture production systems and include: sustainable sources of seed, diet composition (e.g., high fish meal and oil), and environmental impacts (Tucker & Hargreaves 2008). However, cage systems can be under more scrutiny as they often involve public waters and wild populations. Still, considering all the challenges cage aquaculture faces, it remains an excellent culture system for many species. Especially since the development of improved seed production techniques, genetically improved culture strains, improved feed quality, and better knowledge of proper siting considerations.

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